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# EFFLUENT AMMONIA VARIABILITY FROM NITRIFICATION FACILITIES

by

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

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# EFFLUENT AMMONIA VARIABILITY FROM NITRIFICATION PLANTS

Lewis A. Rossman*

A statistical analysis was made on several years worth of daily effluent ammonia concentrations from seven Ohio nitrification plants. Significant seasonal and annual trends were found in six of the plants. The full range of ammonia variability within a season could not generally be fit to any of five commonly used probability distributions. Values above 0.5-1.0 mg/L fit the lognormal or shifted exponential distribution in most cases. Selected exceedance probabilities and concentration percentiles could be related to the overall seasonal mean concentration. These relationships suggested using the exponential distribution as a general model for approximating within-season ammonia variability.

## Introduction

Ammonia discharges from sewage treatment plants can cause direct toxic impacts on aquatic life or indirect impacts due to oxygen demand exerted. The U.S. EPA Needs Survey (6) indicates that the most frequently used form of ammonia removal is biological nitrification. Although the essential design principles of these processes are well established, little is known of how consistently they produce a well-nitrified effluent from day to day. Such information is needed to estimate the protection afforded receiving waters from acute toxic episodes and to establish rational safety factors for design.

This study was undertaken to statistically characterize the daily variability in effluent ammonia levels from existing nitrification facilities. Questions of interest included the presence of seasonal effects, the ability to describe the distribution of effluent ammonia with commonly used probability functions, and the relationship between the mean ammonia level and its daily variability. No attempt was made to find mechanistic explanations for the observed variability although this certainly would be a fruitful area for future study.

## Data Base

Over 3500 days worth of plant performance data were compiled from seven nitrification facilities in Ohio. The source of these data was the plants' Discharge Monitoring Reports stored by the Ohio EPA in their LEAPS data management system. The use of plants only in Ohio may limit the generality of any results of this

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study to areas with similar climatic conditions. On the other hand it serves to eliminate climate as a possible confounding variable.

The general characteristics of the plants are listed in Table 1. Both suspended and fixed growth nitrification processes are represented. All of the plants were loaded at only 40 to 80 percent of their design hydraulic capacity.

TABLE 1. Description of Nitrification Facilities Studied

| Plant | Nitrification Process | Design Flow, mgd | Ammonia Limit, mg/L | |
|---|---|---|---|---|
| | | | Summer | Winter |
| 1 | AS | 20 | 2.5 | - |
| 2 | AS | 4 | 2.5 | 2.5 |
| 3 | TF + AS | 3.6 | 1.5 | - |
| 4 | AS + RBC | 2 | 2.0 | 2.0 |
| 5 | RBC | 2 | 2.0 | 5.0 |
| 6 | RBC | 4 | 1.0 | - |
| 7 | RBC | 7 | 1.6 | - |

AS = Activated Sludge, TF = Trickling Filter,
RBC = Rotating Biological Contactor

Figure 1 gives some idea of how the monthly average effluent ammonia concentration varied over the period of record at a plant, in this case plant 2. The other plants show similar behavior. Figure 2 illustrates what the series of daily effluent ammonia levels typically looks like over a year (May 1977 through April 1978 for plant 2). All ammonia concentrations shown in these figures and throughout this paper are of total ammonia expressed as mg/L nitrogen.

## Seasonality

A distinct seasonal pattern is evident in the monthly average ammonia levels plotted in Figure 1. There also appears to be an improving trend in effluent quality with time at this plant. Analysis of variance tests were applied to each plant to see if the variation in daily effluent ammonia could be attributed to either the year and/or the season in which the data were taken. A two-season year was used with summer consisting of May through October. This corresponds to the seasonal division used by Ohio EPA in stipulating seasonal discharge permit limits.

The analysis of variance results indicated that only one plant (number 1) did not show a statistically significant (5% level) influence of either year, season, or both combined. It therefore appears appropriate to group data at a given plant by both season and year. The statistical properties of these groups should be analyzed separately since they most likely belong to different populations. This grouping produced 51 sets of seasonal data.

## Distribution Analysis

The distribution of daily effluent ammonia levels within a season at a given plant is typified by the cumulative frequency plot shown in Figure 3. These data were taken from plant 2 for the summer of 1977. Note the disproportionate number of values below .3 mg/L. Attempts were made to fit each seasonal data set to five commonly used probability distributions (1) - the normal, log-normal, exponential, extreme value I (Gumbel), and extreme value II. The latter four distributions are all bounded below at zero and are skewed to the left. The Kolmogorov-Smirnov test (5) was used to see how many seasonal data sets would fit each distribution at a 5% level of significance. When all of the data in each set were employed only 37% of the data sets could be fit to one or more distribution. This poor showing can be attributed to the anomalous behavior of the data in the 0-1 mg/L range.

An alternative approach is to assume that the overall distribution of daily ammonia levels in a season consists of a mixture of distributions - one for "completely" nitrified effluents (i.e., concentrations below 1 or 0.5 mg/L) and another for "partially" nitrified days. The distribution of completely nitrified effluent is of less interest than the partially nitrified effluent since its concentration range is so small and is more prone to analytical measurement errors. If p represents the frequency of partial nitrification and $F_p(c)$ the cumulative frequency of partial nitrification to concentration c, then the overall cumulative frequency of effluent concentration c is given by $(1-p) + pF_p(c)$. Using this approach, 97% of the partially nitrified data sets could be fit to one or more of the five distributuons. The log-normal distribution fit 68% of the data sets and the exponential distribution (with origin shifted to the partial nitrification cut-off concentration) fit 56%.

## Relationships to Seasonal Means

General relationships between an ammonia level exceedance frequency or concentration percentile and the overall seasonal mean concentration are useful for developing design safety factors (3). Linear regression analysis was used to establish such relationships for three measures of within-season variability - the exceedance frequency of 1 mg/L, the 90-th percentile concentration, and the 95-th percentile concentration.

Figure 4 indicates a linear correspondence between the logarithm of the 1 mg/L exceedance frequency, F, and the reciprocal of the seasonal mean concentration, $\bar{c}$. The least squares fit line, after transformation, produced the equation $F = 0.8 \exp(-0.83/\bar{c})$ with $R^2 = 0.89$. Figure 5 suggests a linear relationship between the seasonal mean and the 90-th percentile concentration, c90. Least squares regression through the origin produced the equation $c90 = 2\bar{c}$ with $R^2 = 0.94$. A similar regression for the 95-th percentile gave $c95 = 2.4\bar{c}$ with $R^2 = 0.85$. Thus the seasonal mean contains a good deal of information about within-season variability.

General Model

The results of the last section suggest that the cumulative frequency of daily effluent ammonmia levels can be approximated with an exponential relation of the form $1 - \exp(-\beta c/\bar{c})$. The distribution analysis described earlier showed some success in fitting an exponential distribution to "partially" nitrified effluent. If this distribution were extended back to zero to cover the "completely" nitrified values as well, its cumulative distribution function would be $1 - \exp(-c/\bar{c}_p)$ where $\bar{c}_p$ is the mean of the partially nitrified data. When $\bar{c}_p$ was regressed against $\bar{c}$ an estimate of $\beta = 1.02$ was produced with $R^2 = 0.93$. Since this is so close to 1.0, the simple exponential cumulative function $1 - \exp(-c/\bar{c})$ is proposed as a general model for predicting daily ammonia variability within a season.

The dashed lines in Figures 4-5 show how well the exponential distribution predicts the 1 mg/L exceedance frequency and the 90-th percentile concentrations as a function of the seasonal mean. Qualitatively, these lines are close to the least squares fits. Several statistical tests were made to provide a more quantitative assesment. Based on an F-ratio test (4) equality of the exponential model and least squares fit for the 1 mg/L exceedance frequency was significant at a 1% level but not at a 5% level. Equality for the percentile relations could not be established at either level. The exponential model predictions for the two percentiles were compared with the 95% confidence limits on the observed percentiles. These limits were computed using the distribution-free methods described in Ref. 2. Eighty-seven percent of the 90-th percentile estimates and 77% of the 95-th percentile estimates fell within the confidence limits of the observed values. This evidence, along with the goodness-of-fit results from the distributional analysis lend credence to the use of the exponential distribution as a generally applicable approximation for estimating daily effluent ammonia variability.

This conclusion has implications for suggesting general safety factors in the design of nitrification facilities. To meet a given ammonia limit 100F% of the time, the seasonal mean designed for must be $-1/\ln(1-F)$ as large as the limit. E.g., for 95% reliability a safety factor of 3 is suggested.

Appendix - References


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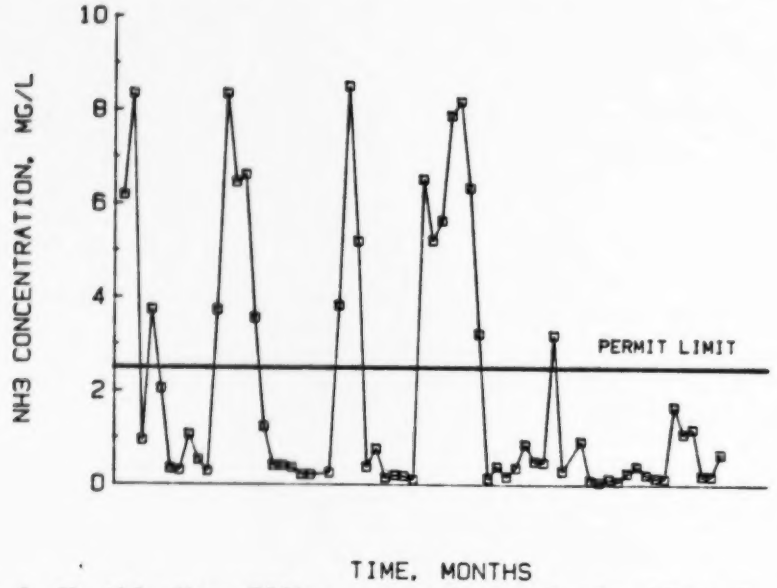


Figure 1. Monthly Mean Effluent Ammonia Levels for Plant 2

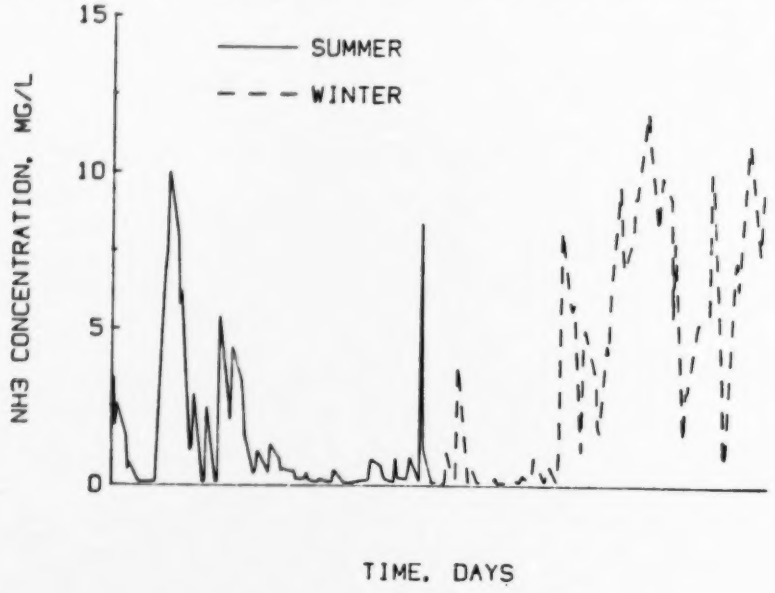


Figure 2. Daily Effluent Ammonia Levels for Plant 2, 1977-78.

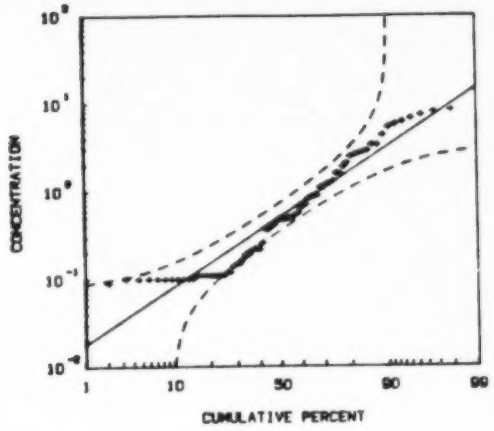


Figure 3. Cumulative Frequency Plot of Summer 1977 Data From Plant 2

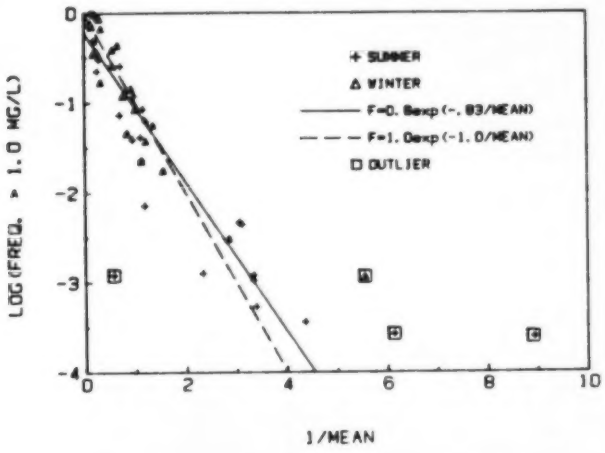


Figure 4. Relation Between Seasonal Mean and 1 mg/L Exceedance

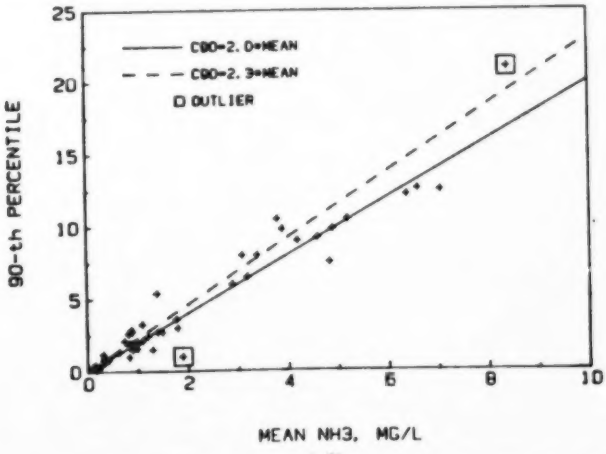


Figure 5. Relation Between Seasonal Mean and 90-th Percentile